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The effects of clear and black plastic mulch on soil temperature, weed seed viability and seedling emergence, growth and yield of tomatoes

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An experiment was carried out from 30 March to 24 August 1994 to compare the effects of clear and black plastic mulch against an uncovered control on soil temperature, weed seed viability and weed seedling emergence and height and yield of tomatoes (*Lycopersicon lycopersicum* L. cultivar Moneymaker). Mean weekly soil temperatures at 2 cm depth at 1400 hrs were highest under the clear plastic and were generally lowest under the black plastic covers. The plastic covers did not affect the viability of weed seeds in soil samples collected from 0–3 and 0–5 cm depths at 6 and 10 weeks after transplanting (WAT) respectively. When the plastic mulch was removed at the end of the experiment, significantly more weeds (P<0,05) had emerged under the clear plastic (324 weeds per m^2;) than in the uncovered control (99 weeds per m^2) and under the black plastic (6 weeds per m^2). Plant height at 12 WAT, number of plants with flowers and fruits at 7 WAT and 10 WAT respectively, were similar in the black and clear plastic treatments, but were lower (P<0,05) in the uncovered control. Yield was similar among the three treatments during the first four weekly harvests but plastic mulching resulted in significantly higher yields (P<0,05) than the control in the last three weeks of harvesting. Cumulative yield over the 7-week harvesting period significantly differed (P<0,01) among the three treatments being 18,6; 14,8 and 7,82 tonnes per ha for the clear plastic, black plastic and uncovered control respectively. The plastic mulching treatments enhanced tomato plant growth and yield by changing the temperature and light micro-environment around the plants.

Key words: plastic mulch, tomato, growth, yield, weed seed viability, weed emergence

Mulching is defined as the application or creation of any soil cover that constitutes a barrier to the transfer of heat or moisture (Rosenberg *et al.*, 1978). Plastic mulches generally affect the microclimate around the plant by increasing soil and, to some extent, air temperatures (Waggoner *et al.*, 1960; Adams 1965). They also change the spectral qualities of light around the plant (Hunt *et al.*, 1989; Decoteau *et al.*, 1990) and suppress soil water loss by evaporation (Wagonner *et al.*, 1960). As a result of the microclimatic changes induced by using plastic mulches of various colours; increases in per cent seedling emergence, growth and yield have been recorded with cucumber, broccoli and lettuce (Peirce, 1987), tomatoes (Wolfe, 1992) and bell peppers (Decoteau *et al.*, 1990).

Other benefits attributable to plastic mulch include enhanced earliness of ripening and yield (Miller, 1968), protection of horticultural crops against frost and the control of weeds (Ballif and Dutil, 1975). However, the specific effects of the plastic mulch on soil and air temperatures and the spectral quality of light and subsequently on growth, earliness of yield and cumulative yield of horticultural crops are dependent on the translucency, reflectivity and absorbance of plastic material used. These parameters are largely controlled by the colour of the plastic mulch (Wagonner *et al.*, 1960; Decoteau *et al.*, 1986; Ham *et al.*, 1993).

The main tomato production period in Zimbabwe is the cool dry season from May to August, avoiding the high humidity and temperature conditions in the wet season from November to March which encourage leaf diseases (Aggrey and Tekie, 1989). Night temperatures during the cool dry season are generally low and occasionally fall below zero which reduces growth, earliness and yield of tomatoes. The experiment was designed to evaluate the effect of clear and black plastic ground mulch on soil temperatures, weed seed viability in the upper soil profile, weed emergence under the plastic covers and growth and yield of tomatoes.

Materials and Methods

Field

Tomato seedlings (cv. *Moneymaker*), sown in asbestos trays in a glasshouse, were hardened by withholding watering until severe wilting occurred for two and half weeks before transplanting. Three similar sized seedlings were transplanted on 30 March 1994 at a spacing of 1 m between rows and 0,5 m between planting stations. They were thinned to one plant per planting station 3 weeks later. Before planting; compound D fertilizer (18 per cent N, 14 per cent P_2O_5 and 8 per cent K_20) was applied at 1000 kg per ha to the planting stations and thoroughly mixed with the soil according to the recommendations of Aggrey and Tekie (1989).

The plastic mulch covers were laid on immediately after transplanting. The mulching treatments were black plastic, clear plastic and the uncovered control organised as a randomized complete block design with four replications. Each of the plastic mulch replicates consisted of a 2,5 x 4 m plastic sheet stretched on the ground with the tomato transplant protruding through 10 cm-diameter holes. This diameter was chosen to allow subsequent operations of watering, top-dressing with nitrogen and stacking to be done without removal of the plastic sheets. The plastic sheets were buried at the edges of the plots to secure them. There were two rows of tomato plants per treatment replicate centrally placed within each of the 2,6 x 4 m plots. Each row had seven plants making a total of 14 plants per replicate.

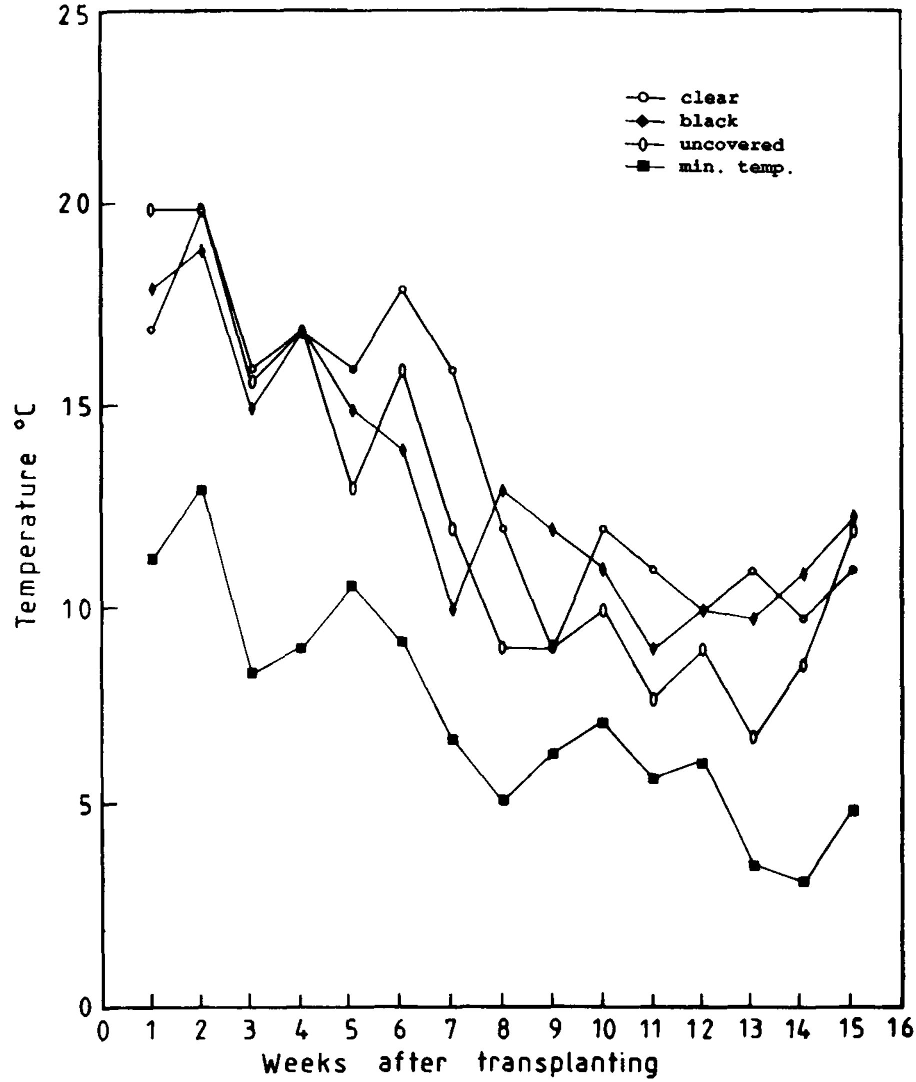
The tomatoes were side dressed with ammonium nitrate (34,5 per cent N) at the rate of 80 kg per ha at 5 WAT. Stacking was started at 7 WAT and new growth was tied to the stacks as the plants continued to grow. A mixture of copper oxychloride and dithane M45 at 400 and 160 g a.i. per ha respectively, were applied at 3 weekly intervals as a prophylactic measure against fungal and bacterial diseases. Dimethoate was applied at 40 g a.i. per ha to control aphids and whiteflies at 6 and 9 WAT.

Soil temperature was measured daily under the plastic treatments and in the control treatment at 2 cm depth. The temperatures were measured at 0800 and 1400 hrs by placing the bulb of mercury thermometers 2 cm deep into the soil through small holes in the plastic covers and allowing the temperatures to stabilize for 20 minutes before readings were recorded. Temperatures were measured from transplanting to 15 WAT when the tomato plants had formed a canopy causing substantial shading of the plastic mulch covers. Tomato plant height was measured from the ground to the tip of the apical meristem at 7 and 12 WAT using a metre rule. Plants were inspected at 7 and 10 WAT to count the number of plants with open flowers and fruit respectively. The yield of red ripe tomatoes was measured weekly from 14 WAT until the tomato plants senesced 21 WAT on 24 August 1994. At removal of the plastic sheets at 21 WAT, three 1 x 1 m quadrants were randomly thrown into each treatment replicate and the number of emerged weeds counted.

Glasshouse

The glasshouse experiment was established to measure the solarization effect of the plastic mulch treatments on weed seeds resident in the upper soil profile. The plastic covers were temporarily rolled back and three soil samples were randomly taken from each treatment replicate from 0–5 cm depth at 6 WAT and 0–2 cm depth at 10 WAT using a spade. Each soil sample was thoroughly mixed and deposited into a 70 x 30 x 6 cm asbestos tray. The trays were laid out as a

Fig 1: Mean weekly soil temperature at 2 cm depth at 0800 hrs for clear and black plastic mulch and uncovered control



min temp = minimum air temperature

randomized complete block design on a bench in a greenhouse maintained at 30° and 20°C day and night temperatures respectively. The soil was kept moist and the number of weeds which emerged from each tray were counted 5 weeks later.

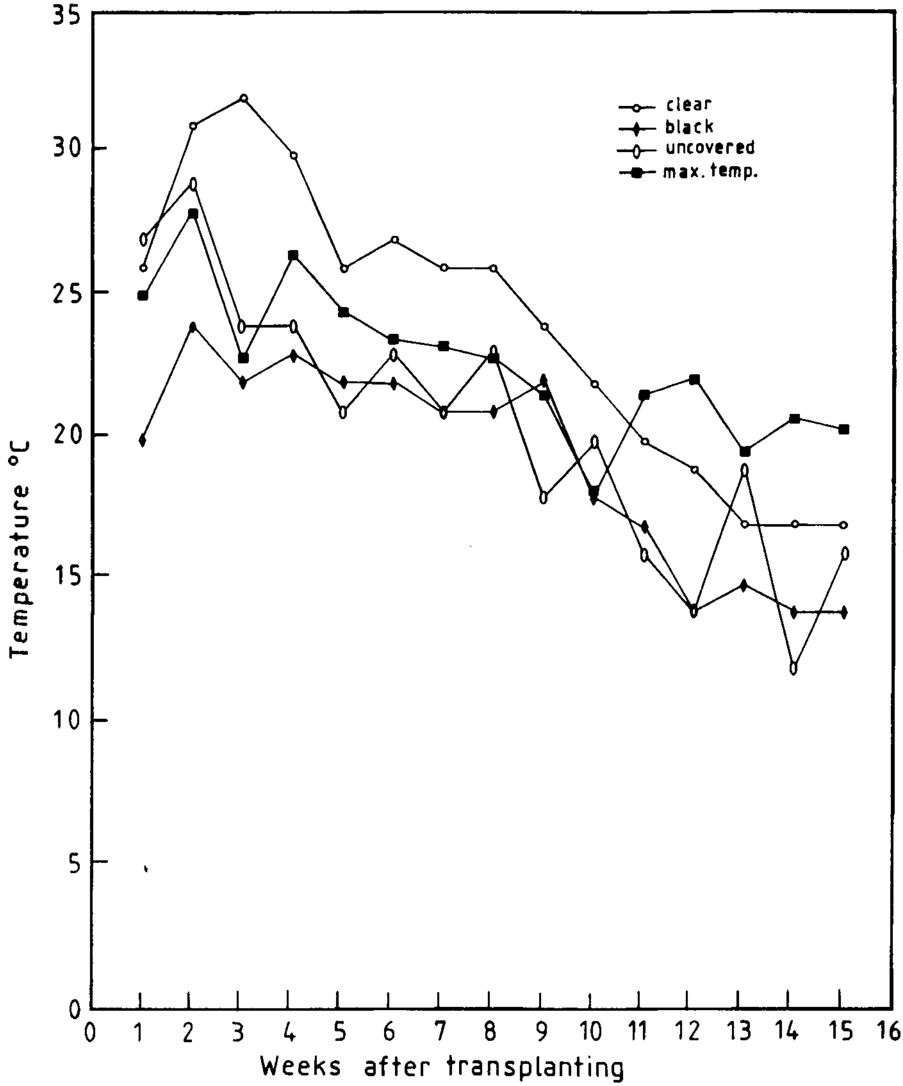
All data, except temperature measurments, were subjected to analysis of variance (ANOVA). Yield was converted to tonnes per ha before analysis. Least significant differences (LSD) at 5 per cent level were used to separate the means where treatment effects were significant.

Results

Soil temperature

The mean weekly soil temperature at 0800 hrs, at 2 cm depth, under the clear, black and in the uncovered control were all higher than

Fig 2: Mean weekly soil temperature at 2 cm depth at 1400 hrs for clear and black plastic mulch and uncovered control



max temp = maximum air temperature

mean weekly minimum air temperature at screen level (Figure 1). Soil temperatures were generally higher under clear plastic but, at weeks 1, 8, 9 and 15, the highest temperatures were found under the black plastic. The lowest mean weekly soil temperatures at 2 cm depth were found in the control but this treatment had higher temperatures at weeks 1, 6 and 7 than those of the black plastic mulched treatments (Figure 1).

The mean weekly soil temperatures at 1400 hrs, at 2 cm depth, were generally highest under the clear plastic mulch but were lower than the mean weekly maximum daily temperature from week 11 to week 15, when the tomato plants had formed a significant canopy (Figure 2). Temperatures under black plastic mulch were consistently lower than under clear plastic mulch throughout the 15-week period. Mean weekly

Table 1: Weed numbers that emerged from soil samples collected from different soil depths and under plastic mulch at removal

	Number of weeds that emerged		
Mulch treatment	From 0–5 cm depth soil samples (6 WAP)	From 0–2 cm depth soil samples (10 WAP)	Under mulch at removal
Clear plastic	368,5a	272,3a	324,0a
Black plastic	327,0a	254,8a	6.0b
Uncovered	324,0a	336,0a	93,8b
Significance	NS	NS	* *
SEM	61,25	43,59	39,98
LSD (P<0,05)	–	–	138,37
CV %	36,05	30,30	56,62

Means followed by a common letter in the same column are not significantly different at P<0.05.

WAP = Weeks after transplanting
NS = Not significant
** = Significant at P<0,01

Table 2: Plant height, number of plants with flowers and number of plants with fruits of tomato plants grown with clear, black plastic mulches and an unmulched control

Mulch treatment	Plant height (cm) at 7 WAT	Plant height (cm) at 10 WAT	Number of plants with flowers 7 WAT	Number of plants with flowers 10 WAT
Clear plastic	13,3a	86,0a	9,5a	13,0a
Black plastic	17,3a	81,0a	9,3a	10,3ab
Uncovered	13,0a	55,0b	5,3b	7,8b
Significance	NS	**	*	*
SEM	1,36	4,06	0,95	0,96
LSD (P<0,05)	–	14,05	3,3	3,3
CV%	16,85	11,13	23,84	18,61

Means followed a common letter in the same column are not significantly different at P<0.05.

NS = Not significant
WAT = Weeks after transplanting
* = Significant at P< 0,05
** = Significant at P<0,01

Table 3: Weekly and total tomato yield for crop grown with black and clear plastic mulches and an unmulched control

	YIELD (t/ha)							
Mulch treatment	WK1	WK2	WK3	WK4	WK5	WK6	WK7	TOTAL
Clear plastic	0,3a	1,4a	2,2a	2,0a	3,8a	4,4a	4,6a	18,6a
Black plastic	0,4a	1,4a	2,1a	2,0a	3,2a	2,6a	3,0a	14,8b
Uncovered	0,2a	1,2a	1,5a	0,9a	1,5b	1,3b	1,3b	7,8c
Significance	NS	NS	NS	NS	*	**	*	**
SEM	0,12	0,30	0,23	0,48	0,55	0,44	0,73	0,95
LSD (P<0,05)	–	–	–	–	1,89	3,06	2,54	3,30

Means followed by a common letter in the same column are not significantly different at P<0.05

NS = Not significant
* = Significant at P< 0.05
** = Significant at P< 0.01

air temperatures were always higher than the mean weekly soil temperatures under the black plastic except for weeks 9 and 10, when temperatures were equal. Higher soil temperatures occurred in the control during the initial four weeks compared to the black plastic treatment. Thereafter, equal temperatures were recorded at weeks 7 and 12, higher soil temperatures were recorded in the control than under the black plastic at weeks 6, 8, 10, 13 and 15; and higher soil temperature occurred under the black plastic than the control at weeks 5, 9, 11 and 14 (Figure 2).

Weed seed viability and emergence under the plastic mulch covers

Mulching treatments had no significant effect on the number of weeds that emerged from soil samples collected from the 0–5 and 0–2 cm depth at 6 and 10 WAT respectively (P>0,05), when the soil samples were incubated in a heated glasshouse (Table 1). However, mulching regime significantly affected the number of weeds that had emerged below the mulch at the time of removal (P<0,01). Significantly higher numbers of weeds emerged from under the clear plastic (324 weeds per m^2) compared to the uncovered control (94 weeds per m^2) and the black plastic treatment (6 weeds per m^2). There was no significant difference between the black plastic treatment and the uncovered control (Table 1).

Growth and yield of tomato plants

Plant height at 7 WAT did not significantly differ among the three treatments (Table 2). However, at 10 WAT, the tomato plants in the clear and black plastic mulching treatments had significantly grown taller than those in the uncovered control (P<0,01). Visual assessments made at 10 WAT indicated that the tomato plants in the mulched treatments were more bushy indicating more branching and foliar growth than those in the control. The number of plants which had flowered at 7 WAT and those that had fruits at 10 WAT per treatment replicate was used as an indicator of earliness. The plastic mulching treatments (black and clear) had significantly more plants in flower at 7 WAT (P<0,05) and more plants with fruits at 10 WAT than the uncovered control.

However, the earlier flowering and fruiting in the mulched treatments were not reflected as early yields. Weekly yields of red ripe tomatoes were not significantly different in the first four weeks of harvesting (Table 3). In the last three weeks of harvesting, the highest yields were obtained from the clear plastic mulch, although they were not significantly different from the black plastic mulch. The uncovered control had significantly lower yield in this period ($P<0,05$) than both the clear and black plastic mulch. Total cumulative yield significantly differed among the three treatments ($P<0,01$). Total cumulative yield was highest in the clear plastic treatment followed by the black plastic mulch treatment and then the uncovered control (Table 3).

Discussion

Average weekly soil temperatures at 0800 hrs reflect the role of the ground as a heat storage body. Mean weekly soil temperatures were warmer for the mulch treatments than for the control and the mean weekly minimum air temperatures. Morning temperatures were higher in the mulched treatments because the air gap between the soil and mulch reduced convective heat transfer to the surrounding air. The plastics trapped a portion of the outgoing longwave radiation emitted from the soil and they prevented evaporative cooling on the mulched surfaces (Ham *et al.*, 1993; Waggoner *et al.*, 1960). However, the clear plastic mulch generally had higher soil temperatures at 0800 hrs than the black plastic treatment. Ham *et al.* (1993) reported that clear plastic mulch builds up higher temperatures in the air and soil under it during the day but traps outgoing radiation as effectively as coloured plastic mulch. Deposits of water droplets which form by condensation on the underside of plastic covers at night trap outgoing radiation (Ham *et al.*, 1993).

In the first 10 WAT, before canopy closure shaded out the surface of the plastic mulches, the clear plastic treatments consistently had higher soil temperature at 1400 hrs than the other two treatments. The clear plastic film and water droplets beneath it conserve energy by stopping evaporation and retarding the loss of thermal radiation from the soil while at the same time permitting the transmission to the soil of any incoming short-wave radiation which is absorbed and converted to sensible heat at the soil surface (Wagonner *et al.*, 1960). On the other hand, mean weekly soil temperatures at 1400 hrs were generally lowest under the black plastic mulch. The black plastic mulch does not transmit insolation through but converts it to sensible radiation, causing the surface of the plastic mulch to gain heat (Ham *et al.*, 1993). The increased temperature of the black plastic surface increases thermal radiation exchange by conduction and convection to the surrounding air. The layer of air beneath the plastic, with its low conductivity, prevents the high surface temperature of the plastic mulch from being transferred to the soil surface (Wagonner *et al.*, 1960). Higher soil temperatures have been recorded under black plastic than under clear plastic when the plastics are tightly stretched and in contact with the soil ensuring direct transfer of the higher temperatures attained by the black plastic to the soil (Ham *et al.*, 1993). In this experiment, the plastics were laid loosely over the soil.

In the last five weeks of temperature measurements, higher mean maximum air temperatures were measured than soil temperatures at 2 cm depth in the clear or black plastic and uncovered treatments because of the effects of shading.

Both the clear and black plastic mulches did not reduce weed seed viability in the upper soil profile by solarization as the temperatures that developed under them were not high enough to kill weed seeds in the soil. Weed seed of most species must be exposed to temperatures of above 40^{O}C before mortality occurs (Bewley and Black, 1982). The results indicate that laying clear and black plastic loosely on the soil surface is unlikely to be useful to kill weed seeds in the soil by solarization as ambient temperatures in Harare will be low from March to August.

Weed emergence under the clear plastic was approximately three and 50 times that of the control and black plastic respectively. Clear plastic allows light transmission to the soil surface and maintains high soil germination of most weed species when moisture is available (Egley and Duke, 1985). Black plastic does not transmit light to the soil surface, preventing the germination of positively photoblastic weed seed. Any seedling which emerges under the black plastic will etiolate because of lack of light and eventually die. Wolfe (1992) pointed out that the biggest disadvantage with clear plastic mulch is weed control. However, black plastic mulch is one of the best weed control measures farmers can use.

The higher weekly and cumulative yields obtained in the plastic mulch treatments than the uncovered control are because the plastic mulched plants were taller and therefore provided a bigger framework for flowering and fruiting points to develop. The higher growth rate and yield obtained with the plastic mulch treatments are not only explainable in terms of their influence on soil temperature. Despite the lower soil temperatures obtained under the black than the clear plastic mulch at both 0800 and 1400 hrs, these treatments had similar plant height and weekly yields. Tomato plants grown with black plastic mulch produced more leaves and petioles and had longer internode lengths than unmulched treatments (Decoteau *et al.*, 1986), resulting in taller and bushier plants, as was observed in this experiment. Ham *et al.* (1993) found that the temperature of the air 5 cm above black plastic mulch was 4–5^{o}C higher than air at 1,5 m (screen height) and such changes in near surface temperature above the plastic mulched treatments, especially the black plastic may partially be responsible for the increased growth and yield in the plastic mulched treatments compared to the control in this experiment. In addition, plastic mulches transmit, absorb, emit and reflect different wavelengths of radiation depending on their colour and this influences plant morphogenesis and growth (Decoteau *et al.*, 1990; 1986; Ham *et al.*, 1993). Although no spectral measurements were made in this experiment, changes in the spectral quality of light around the plant caused by the plastic covers, may have conferred the growth and yield advantages obtained with the plastic mulched treatments over the control. Plastic mulch effects on near surface temperatures and the quality of light around the plant have been demonstrated to be more influential on plant growth, morphogenesis and yield than their effects on soil temperatures in bell peppers (Decoteau *et al.*, 1990) and tomatoes (Decoteau *et al.*, 1986).

Conclusions

Plastic mulches did not have a significant solarization effect on weed seeds at 0–5 cm depth in the soil but the clear plastic stimulated weed emergence while very few weeds emerged under the black plastic. Although soil temperatures were generally higher under clear plastic than under black plastic mulch; height, earliness and weekly yield of tomatoes were similar, suggesting that the reflective and near surface temperature effects of the plastic mulches were partially instrumental in causing the growth and yield responses of the tomatoes. Further research, under Zimbabwean conditions, needs to be done using a wide range of plastic colours, at different times of the year and with different horticultural crops to evaluate the feasibility of using this technology to enhance horticultural production.

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